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Performance Analysis in Strength Training: An Innovative Instrumentation

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Abstract

In strength training, the performance of the athletes varies according to different objectives of the training. In this study, the performance of the athlete in strength training is defined as the torque and power generated to lift given loads. Electromyography (EMG) is utilized during the performance assessment to prevent muscle injuries. Over the past few years, athletic and clinical testing on performance analysis and enhancement have traditionally taken place in the laboratory due to the low portability of the equipment. With the rapid development in electronics miniaturization, instrumentation for such data acquisition can be constructed in mini and micro scale. Miniaturized instrumentations are designed to be unobtrusive to athletes' movement during performance analysis and enhancement. On the other hand, the correlation between muscle activity and real-time data for performance assessment is critical for coaches and physiologists. With the aid of a miniaturized system that can correlate the muscle activity with performance, fatigue, impulse and total energy expenditure, coaches and physiologists can plan the most suitable training for athletes to achieve higher performance. In conclusion, this study focuses on the miniaturized instrumentation for the analysis of athletes' performance in strength training.

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Keywords: Strength Training, Performance Analysis, Instrumentation, EMG, Muscle Fatigue

1. Introduction

Strength training is a type of exercise that specializing in using resistance to induce the muscular contraction which helps to build the strength, anaerobic, and size of skeletal muscles.[1]

Sports, where strength training plays a vital role, are for instance bodybuilding, weightlifting, powerlifting and javelin throw. Other notable sports that also uses strength training as part of their training regimen are American football, wrestling, rugby, track and field, rowing, lacrosse, basketball, pole dancing (or pole fitness) and hockey. Strength training is becoming increasingly popular for other sports and physical activities.[2] Hence, performance analysis of the athlete becoming a vital part of maintaining the condition of the athlete. Performance Analysis is an approach that involves systematic study to improve the performance and decision making, primarily presented through the provision of data analysis or visual feedback.[3,4]

To gather data more efficiently, instrumentation plays an important role. Instrumentation is an approach that comprises the development of the instrument to measure physical quantities for monitoring, control and observation.[5] Currently, hand–held, personal digital assistance (PDA)-based physiological data acquisition systems have progressively become more common in daily applications due to their portability, decreasing price, enhanced product performance, robustness, signal accuracy, lesser

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weight and extensibility.[6] In sports, there are a number of commercial systems available for measuring muscle disorder, muscle strength, biofeedback muscle stimulation, monitor the exercised segment peak velocity and other sporting concerns.[7]

Electromyography, which is also known as EMG, is an electrodiagnostic technique for evaluating and recording the electrical activities that produced by skeletal muscles.[8] Some critical features from well-known EMG system vendors include real-time visualization of results, connection to a computer and a sensor, portability, PDA-based user-friendly software with visible GUI, low cost, usage capability in different parts of the body.[9] Previous work reflects the importance of the features above in the design of both portable and non-portable physiological monitoring devices. Burns et al. developed a wireless physiological signal monitoring system with EMG and ECG sensors for monitoring human movement and sleep, the device can be operated both by a desktop computer and a mobile phone. Hand-held physiological monitoring system demand is growing, however, research in that area is much to be desired.

Meanwhile, the intensity of the training is also a critical factor that may lead to muscle fatigue.[10] Muscle fatigue is the inability of the muscle to generate force and to maintain the contraction to carry out high-intensity training.[11,12] Recent studies suggested that linear acceleration, which can be measured by accelerometer or Inertia Measuring Unit (IMU) can be defined as the intensity of training.[5] Linear acceleration data collected through IMU can be a valuable information for the coaches to monitor the performance of the athlete.[13]

This papers proposed an instrumentation approach for monitoring the performance of athletes for free weight weightlifting by using a combination of Inertia Measuring Unit and EMG Sensor.

2. System Overview

This prototype system consists of a smartphone, a computer and two types of wearable sensors. In such setting, the smartphone serves as the hub for collected data from accelerometer real time and computer act as the device to gathered EMG data before both data are processed offline on the computer. Additionally, such setting allows transfer of data and processed results that enable real-time supervision of the training by rehabilitation specialists or personal trainers.

A 6 degree of freedom accelerometer was mounted on the dumbbell. The sensors sample the acceleration data with a sampling frequency of 100 Hz in order to prevent the sensors from experiencing overheat. Meanwhile, a Shimmer EMG sensor has been attached to the subject where the electrodes were attached at the Biceps of the subject to measure the muscle activities as shown in Fig 1.

All sensors were mounted by using standard sports equipment, such as Velcro strap. The installation of these sensors is relatively low-cost as compared to existing equipment. Furthermore, the attachment of the sensors does not obstruct the training in any way.

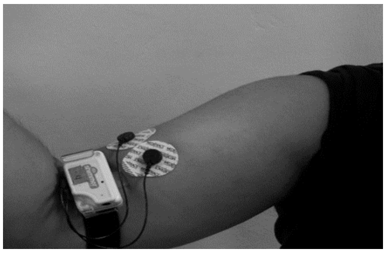


Fig 1. Attachment of Electromyography Sensor's Electrodes to the Bicep of the subject.

3. Methods

3.1. Participants

Three undergraduate male students of the age of 23 years old participated in the study. All three participants had prior strength training experience with the dumbbell during basketball team workout. The subject characteristic is presented in Table 1.

Table 1. The characteristic of the participants for the experiment.

Characteristic	Info
Gender	Male
Numbers	3
Age (years)	23
Height (m)	1.72 ± 0.09
Weight (km)	75.4 ± 8.4

Dominant Hand	Right Handed = 2 Left Handed = 1

3.2. Sensor Validation

In this experiment, the accelerometer with gyro sensor was developed to record the data of the linear acceleration and also the angular velocity. In order to validate the accuracy of the accelerometer, the accelerometer was attached to the dumbbell together with the Shimmer Gyro Sensor. Then, a simple weight lifting training was performed, and the data of both sensors were recorded. Then, a statistical analysis was carried out by comparing both data gathered from both sensors.

Fig. 2. Attachment of Accelerometer and Shimmer Gyro Sensor to the dumbbell for validation.

3.3. Experimental Procedures

According to research done by Stone et al., the intensity in strength training can be defined as the linear acceleration of the dumbbell[3]. This experiment protocol is similar to the one carry out by the former. However, the parameter such as duration of the experiment will be adjusted accordingly to avoid injury of subjects. Participants were asked to report to the laboratory on two separate days. On Day 1, the experiment was thoroughly explained to all the participant. The participant was then asked to complete a questionnaire regarding the experiment indicating their height, weight, arm length and hand dominance and their training experience by using a dumbbell. Any neuromuscular issues that would affect performance during the experiment were also determined, rendering those subject ineligible to participate.

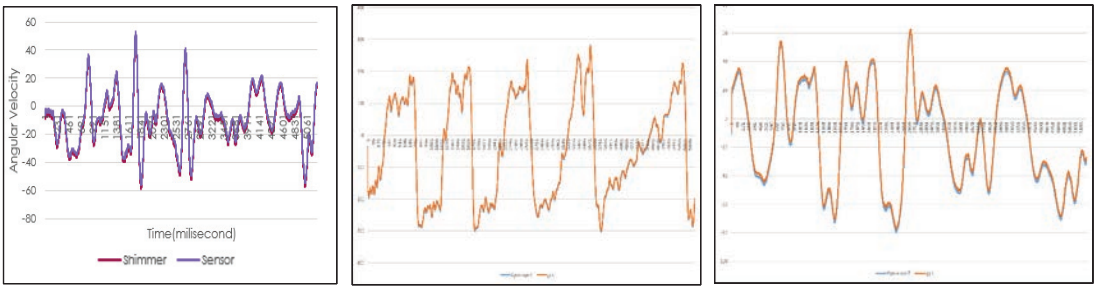
On the second day, participants were asked to carry out simple warm up stretching to avoid muscle injury during the experiment. Then, they were instructed to perform weight lifting by using a 15lbs dumbbell which they will carry out during the experiment. Before the experiment started, all the participants were asked to complete a Rated Perceived Exertion (RPE) form. The participant was required to select the rate in the scale provided for their feedback on the intensity of the experiment. After that, the participant was asked to carry out the experiment by doing weightlifting using a dumbbell for 10 minutes according to their pace. There will be a total of 3 sets of lifting with a 1 minutes' gap for resting and the participant had to increase their pace for every single set.

The data of both accelerometer and electromyography (EMG) sensor will be collected for statistical analysis, which is a correlational statistical test. EMG data was collected and analyzed by using Matlab. At the same time, accelerometer data was collected by using a Bluetooth Module app from a smartphone. The result from both sensors was compared and presented graphically.

4. Result

4.1. Experimental Validation

The accuracy of the 6-axis accelerometer was evaluated with respect to the intensity of the angular velocity motion recorded by comparing the data recorded with Shimmer Gyro-Sensor as illustrated in Fig 3. To achieve a higher accuracy, both sensors are attached at the same position to the dumbbell. The data recorded will then transferred to a computer for analysis. The results, presented suggests that the data recorded by both sensors are almost identical, where the difference of data is less than 5% for both x and y-axis. This further indicates that the developed accelerometer has high accuracy and suitable for this experiment.



(a) (b) (c)

Fig 3. (a) Angular velocity for the x-axis, (b) Angular Velocity for the y-axis, (c) Angular Velocity of the z-axis.

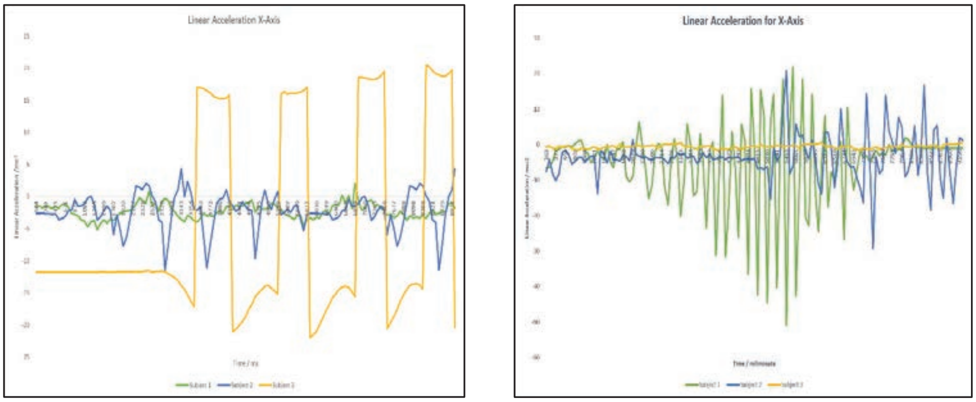
4.2. Intensity Versus Muscle Fatigue

Finally, we investigate how the intensity of training impact the muscle fatigue of the subject. In this study, the intensity of the training is based on the linear acceleration of the dumbbell as shown in Fig 4(a) to Fig 4(f). Meanwhile, the muscle fatigue was determined by the zero-crossing value for each Electromyography (EMG) burst recorded by Shimmer EMG Sensor.

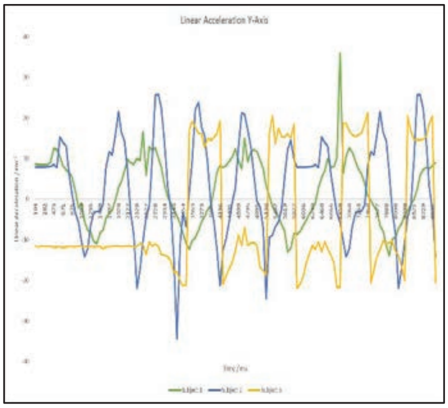
To evaluate how the training intensity influence the muscle fatigue level, the subject was asked to carry out weight lifting at their own preferred pace and fast pace. The experiment began with the preferred pace weight lifting and repeated by lifting the dumbbell at a faster pace. In the experiment, a fast pace swing defined in the experiment is set as at least three swings per 10 seconds.

The result shows that the consistency of the linear acceleration of dumbbell was disrupted once the lifting pace is increased as shown Fig 4(c) and Fig 4(d), respectively. On the other hand, at a higher pace or intensity, the zero-crossing level was found to be decreasing linearly before undergoing rapid reduction as shown in Fig 4(h). In EMG zero-crossing level, our focus was on data from 7th minute to 7.5th minute where a rapid reduction in zero-crossing level happen for subject 1, 2 and 3.

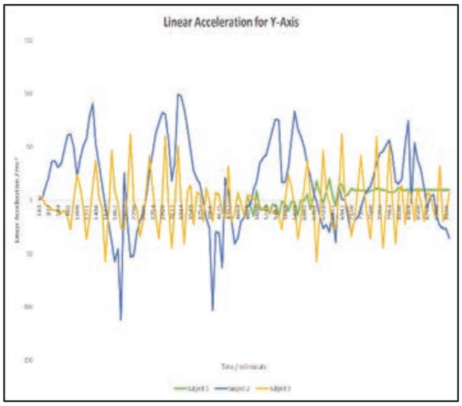
In Fig 4(b), 4(d) and 4(f), it is shown that the intensity of the weight lifting is increased compared to Fig 4(a), 4(c), and 4(e) in terms of linear acceleration. The point where the rapid decreasing in zero-crossing is the point where the subject begins to experience fatigue.



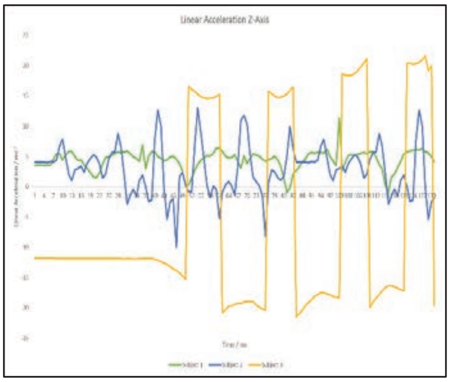
(a) (b)



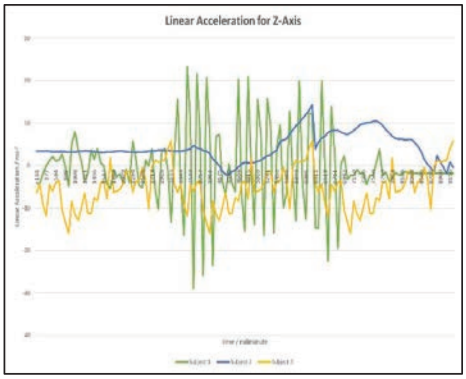
(c)



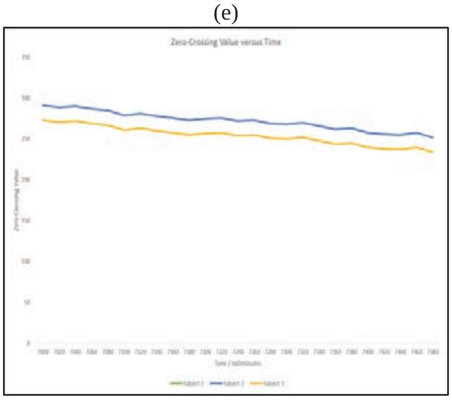
(d)



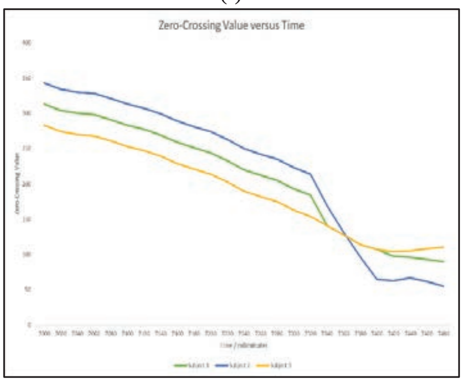
(e)



(f)



(g)



(h)

Fig 4. (a) Linear acceleration of x-axis for slower pace dumbbell lifting, (b) Linear acceleration of x-axis for faster pace dumbbell lifting, (c) Linear acceleration of y-axis for slower pace dumbbell lifting, (d) Linear acceleration of y-axis for faster pace dumbbell lifting, (e) Linear acceleration of z-axis for slower pace dumbbell lifting, (f) Linear acceleration of z-axis for faster pace dumbbell lifting, (g) EMG zero-crossing rate for slower pace dumbbell lifting, (h) EMG zero-crossing rate for faster pace dumbbell lifting.

5. Discussion

The results obtained clearly show that the wearable accelerometer and EMG sensor present a promising technology for performing real-time automated training assessment and analysis. In general, the accuracy of the developed accelerometer is relatively good as it is able to produce results that vary less than 5% as compared to Gyro Sensor available in the market. It is worth to note that the error may not be consistent across different type of exercises since the validation experiment was done on weight lifting only. However, even in worst case scenario, the accelerometer is still able to correctly record the data for weight lifting, whilst ensuring a minimum of 5% error when performing intensity prediction. To eliminate the noise interference, Kalman Filter was employed into the sensor. This countermeasure ensures the data collected can be analyzed smoothly.

The zero-crossing recorded from EMG data is not so consistent as compared to the accelerometer data. This is possibly due to the disadvantage of post processing of the EMG data where the selection of initial point and end point of the burst. Since there is surrounding interference towards the EMG, it is hard to justify the initial point and end point of the EMG burst. Although we can apply filter into the EMG data, some critical data might have filtered away together with the interference during the process. This will affect the accuracy of the data collection and impact towards the results of the muscle fatigue analysis.

From the result, although subject 3 swung at a faster pace as compared to the other two subjects in the experiment, however, the zero-crossing level did not undergo rapid reduction as others. This is due to the fitness of the subject that shows that he is more suitable for higher intensity. At the same time, for the data collected for preferred swing pace of subject 3, the initial data was not collected properly, this is due to the malfunctioning of the accelerometer. Hence, it affects the data of that particular subject as the data maintained abnormal for almost 3 minutes.

This system is advantageous as it exhibits the intensity and muscle fatigue of the athlete during training sessions. This would allow coaches can make a better decision in selecting the suitable training intensity to avoid over-training that might lead to injury. At the same time, by comparing both results, coaches will be able to study and monitor the condition of the athlete, in turn assisting the athlete to achieve peak condition during competition. However, this system requires post-processing, which will delay the duration of a coach in decision making which will affect the training of an athlete. Furthermore, it is also evident that EMG data is not comparable by daily basis due to the different condition of the body, which will also affect the decision making of the coaches in monitoring the performance of the athlete.

6. Conclusion

This study has proposed an approach that uses a network of wearable sensors along with a smartphone to monitor exercise intensity for a set of weight lifting exercise. A 6-axis accelerometer was developed to record the intensity data whilst the muscle activities were measured by using EMG sensor. The sensor transmits the data to a smartphone before being send to computer for post-processing analysis. In terms of accuracy of the accelerometer, the data has been validated with less 5% of error, and this shows that the data recorded by the accelerometer is valid. The results are comparable to the muscle activities decreasing with the increasing in intensity of the training. Future works would include additional exercise quality parameters, such as exercise posture and dynamics. At the same time, we plan to improve the algorithm in order to reduce the number of equipment used by letting the smartphone perform the post processing to get real-time results and improve the portability of the system.

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References

1. Storey A, Smith HK. Unique aspects of competitive weightlifting: Performance, training and physiology. *Sport Med* 2012; 42: 769–790.
2. Gamble P. Periodization of Training for Team Sports Athletes. *Strength and Conditioning Journal* 2006; 28: 56.
3. Stone MH, Sands W a., Pierce KC, et al. Relationship of maximum strength to weightlifting performance. *Med Sci Sports Exerc* 2005; 37: 1037–1043.
4. Ho LK, Lorenzen C, Wilson CJ, et al. Reviewing current knowledge in snatch performance and technique: the need for future directions in applied research. *J Strength Cond Res*; 28: 574–586, http://www.ncbi.nlm.nih.gov/pubmed/23719504 (2014).
5. Kipp K, Harris C. Patterns of barbell acceleration during the snatch in weightlifting competition. *J Sports Sci*; 1–5, http://www.ncbi.nlm.nih.gov/pubmed/25530037 (2014).
6. Fei D-Y, Zhao X, Boanca C, et al. A biomedical sensor system for real-time monitoring of astronauts' physiological parameters during extra-vehicular activities. *Comput Biol Med*; 40: 635–42, http://www.ncbi.nlm.nih.gov/pubmed/20519129 (2010, accessed 20 December 2014).
7. Sun B, Chen W, Zheng X. The System Design for the Extraction and Pre-processing of Surface EMG. *Phys Procedia*; 33: 8–13, http://linkinghub.elsevier.com/retrieve/pii/S1875389212013363 (2012, accessed 15 December 2014).
8. Konrad P. The abc of emg. *A Pract Introd to Kinesiol …*; 1–60, http://demotu.org/aulas/controle/ABCofEMG.pdf (2005).
9. Ahamed NU, Sundaraj K, Poo TS. Design and development of an automated, portable and handheld tablet personal computer-based data acquisition system for monitoring electromyography signals during rehabilitation. *J Eng Med* 2012.
10. Place N, Yamada T, Bruton JD, et al. Muscle fatigue: From observations in humans to underlying mechanisms studied in intact single muscle fibres. *European Journal of Applied Physiology* 2010; 110: 1–15.
11. Halson SL, Jeukendrup AE. Does overtraining exist? An analysis of overreaching and overtraining research. *Sports Medicine* 2004; 34: 967–981.
12. Fry RW, Morton AR, Keast D. Overtraining in athletes. An update. *Sports Med* 1991; 12: 32–65.
13. Yussof S, Hasan N, Wilson B. BIOMECHANICAL ANALYSIS OF THE SNATCH DURING WEIGHTLIFTING COMPETITION. *ISBS - Conference Proceedings Archive*; 1, https://ojs.ub.uni-konstanz.de/cpa/article/view/705 (2002).